Use of the boundary element method for the determination of soil permeability from field tests

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Abstract

This paper is concerned with the use of the boundary element method for the determination of the soil permeability from field tests. It is composed of two parts. In the first, we present the advantage of the boundary element method in the determination of the shape factor used in the identification of the soil permeability from field tests. The second part contains a study of the influence of some factors such as the extension of the soil massif and the soil stratification on the determination of this factor.

1 Introduction

The resolution of various geotechnical and environmental problems requires a good determination of the soil permeability. Presently, this determination is performed from field tests, particularly the constant-head test which constitutes a rapid and simple means for the determination of the soil permeability. This test is based on the measurement of the evolution of the hydraulic potential in a drilled borehole. The interpretation of this test is carried out according to the Hvorslev equation:

\[ Q = F k H_d \] (1)
where $Q$ is the flow rate, $H_d$ is the difference in hydraulic potential, $k$ is the permeability of the soil and $F$ is the shape factor which stands for the interaction between the soil massif and the cavity. Using analytical, numerical and experimental developments, different expressions were proposed for the evaluation of this factor. The first expression is due to Hvorslev (1951):

$$F = \frac{2 \pi L}{\ln \left( \frac{L}{D} + \sqrt{\left( \frac{L}{D} \right)^2 + 1} \right)}$$

This formula results from the resolution of the Laplace equation in an infinite domain for a cylindrical probe of length $L$ and diameter $D$.

Using experimental and numerical developments, other values where proposed for the shape factor. Smiles and Youngs [5] investigated the shape factor using an electric analogy technique. Wilkinson [7] and Raymond & Azzouz [2] used finite difference method. The earliest shape factors were derived from finite element method by Tavenas et al. [6], see the results shown in Figure 1.

Figure 1: Values proposed for the shape factor from previous analytical, experimental and numerical investigations.
Analysis of these expressions shows an important scatter which may induce high uncertainties in the determination of the soil permeability (up to 100%). This scatter can be attributed to several factors, mainly numerical errors induced by the discretization of the Laplace equation and the modelling of the boundary conditions, particularly at the bottom of the borehole (permeable or impermeable) and the position of the lateral boundary.

2 Comparison of the boundary and finite element methods

In this section, we propose to compare the performance of the boundary and finite element methods in the calculation of the shape factor for the typical case illustrated in Figure 2. Numerical simulations were performed assuming axisymmetric conditions and for a homogeneous and isotropic soils. A cylindrical cavity was considered with a permeable condition at both lateral surfaces and at the bottom. The hydraulic potential was maintained constant at the upper surface and at the surface of the cavity. The other boundaries were considered to be impermeable. In this example, we considered the following values for the length (L) and the diameter of the cavity (D) : L = 1 m, D = 0.12 m. The height of the water table (H) was assumed to be 10D, the impermeable base was placed at a distance S = 6D from the bottom of the cavity. Constant elements were used in the boundary analysis while isoparametric 8-node elements were used in the finite element calculation.

Results obtained for two values of R (10D and 40D) are given in Table 1. It can be observed that the results obtained with the boundary and finite element methods are in good agreement. In order to obtain this agreement, we had to use a very refined finite element mesh near the cavity and this induces a high number of degrees of freedom in comparison to those required with the boundary element method. The ratio between the number of degrees of freedom used in the finite element method to that used in the boundary element modelling is about 30. These examples show that the boundary element method constitutes an efficient means for the calculation of the shape factor.
3 Parametric study

In this section we present a study of the influence of some factors on the determination of the shape factor. First, we present the influence of the extension of the soil domain and then we give some results concerning the influence of the soil stratification on the shape factor. This study was performed with the data given in Figure 2 and again the base of the soil massif was assumed impermeable. It was located at a distance $S = 6D$ from the bottom of the cavity and this distance was fixed after a preliminary study which showed a stabilization of the shape factor at this distance.
3.1 Influence of the extension of the soil domain

Numerical simulations were performed in order to study the influence of the lateral extension on the shape factor. Figure 3 shows results obtained for various values of the ratio \( H/D \) (\( H \): height of the water table, \( D \) diameter of the cavity). It can be observed that the shape factor is affected by both the distance of the lateral boundary and the height of the water table. For a given ratio of \( H/D \), we observe an important increase in the shape factor with the extension of the lateral boundary followed by a stabilization. The latter is observed at a distance which depends on the height of the water table. This distance increases from 35\( D \) to 100\( D \) when the height of the water table increases from 10\( D \) to 100\( D \). These results show that care must be taken in locating the position of the lateral boundary which must be placed sufficiently far from the position of the cavity to ensure the condition of an infinite lateral extension.

![Figure 3: Influence of the height of the water table (H) and the lateral extension of the soil massif (R) on the shape factor. Results obtained by the boundary element method.](image-url)
3.2 Influence of the soil stratification

Interpretation of field tests performed in stratified soils requires the use of a shape factor which takes into consideration this stratification. Figures 4a-b show the evolution of this factor in a bi-layered soil. It can be observed that this factor largely depends on the position of the cavity with regard to the interface of the stratification and on the ratio of the permeability of the layer including the cavity to that of the second layer.
Conclusion

In this paper the determination of the shape factor as used in the expression for the soil permeability from field tests is investigated. Numerical tests show that the boundary element method constitutes an efficient mean for the determination of this coefficient.

A parametric study showed that the shape factor largely depends on the position of both the lateral boundary and the water table. For a stratified soil, it was shown that this coefficient undergoes an important variation near to the interface of the two materials.
References